RADIATION EXPOSURES ASSOCIATED WITH SHIPMENTS OF FOREIGN RESEARCH REACTOR SPENT NUCLEAR FUEL

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Summary

In accordance with the *Record of Decision on a Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* (ROD) (DOE, 1996a), the U.S. Department of Energy (DOE) is implementing a 13-year program under which DOE accepts foreign research reactor spent nuclear fuel (SNF) containing uranium that was enriched in the United States. The ROD required that DOE take several steps to ensure low environmental and health impacts resulting from the implementation of the program. These efforts mainly focus on transportation related activities that the analysis of potential environmental impacts in the *Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel* (EIS) (DOE, 1996b) identified as having the potential for exceeding current radiation protection guidelines. Consequently, DOE issued a Mitigation Action Plan to reduce the likelihood of potential adverse environmental impacts associated with the policy established in the ROD.

As shown in the EIS, incident-free radiation exposures to members of the ship's crew, port workers, and ground transportation personnel due to shipments of spent nuclear fuel from foreign research reactors are expected to be below the radiation exposure limit of 100 mrem (1 mSv) per year established to protect the general public. However, the analysis in the EIS demonstrated that port and transportation workers could conceivably receive a cumulative radiation dose above the limit established for the general public if, for example, they are involved in multiple shipments within one year or if the radiation levels outside the casks are at the maximum allowable regulatory limit (10 mrem/hr [0.1 mSv/h] at 2 meters from the surface of the cask).

With the program successfully underway, DOE has collected information from the shipments in accordance with the Mitigation Action Plan. The information to date has demonstrated that the analysis in the EIS of potential impacts associated with marine transport of spent nuclear fuel was very conservative and that actual doses received by workers are much lower than expected. The DOE will continue to monitor cask dose rates and personnel exposure in accordance with the Mitigation Action Plan, but experience has demonstrated that the current practices towards transport of the spent fuel are sufficient for radiation protection purposes. The requirements of the current version of the Mitigation Action Plan reflect the fact that: (1) cask dose rates are much lower than expected, (2) fewer shipments per year are being received, and (3) ship's crew activities are in practice different than assumed in the EIS. However, the limited number of ships currently available to transport spent nuclear fuel and the potential for exposure of ship's crew to dose levels in excess of appropriate regulatory limits requires that DOE maintain a Mitigation Action Plan.

Introduction

On May 13, 1996, the U.S. Department of Energy issued a Record of Decision on Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel. The goal of the long-term policy is to recover enriched uranium exported from the United States, while giving foreign research reactor operators sufficient time to develop their own long-term solutions for storage and disposal of spent fuel. The spent fuel accepted by the US. DOE under the policy must be out of the research reactors by May 13, 2006 and returned to the U.S. by May 13, 2009.

The Record of Decision was supported by a lengthy Environmental Impact Statement (EIS) which analyzed the potential environmental and public health implications of the spent fuel acceptance program. The EIS identified as a potential impact the possibility that members of the public working on the transport of the spent fuel could exceed the annual exposure limit of 100 mrem (1mSv). Members of the public included in this group of workers includes ship crew, dock workers, and truck drivers. In response to the concern that these working members of the public may exceed the annual exposure limits established for the general public, the DOE has developed and implemented a Mitigation Action Plan. This plan requires that the DOE evaluate and track public transportation worker exposures and take action if there is a possibility that a non-radiation worker may exceed 100 mrem (1mSv) in any one year.
Because the EIS estimated that the greatest potential doses for transportation of the foreign research reactor spent fuel could be experienced by ship's crew members, the methodology to estimate the exposures of ship's crew members involved in the marine transportation of the foreign research reactor spent nuclear fuel will be described in this paper, as well as the requirements of the Mitigation Action Plan. The actual and estimated doses personnel have received as a result of shipments will be presented and comparisons made with the estimates made in the EIS. The paper will discuss the appropriateness of the dose estimation methodology used in the EIS and the conservatism that insures protection of those specific groups of the public.

The EIS Analysis of Marine Transport Impacts

The concern that the exposure limit for members of the public involved in the transport of foreign research reactor spent nuclear fuel could be exceeded came from assumptions made during preparation of the EIS. To establish maximum impacts for transportation related workers not designated as radiation workers, radiation exposure estimates are purposely conservative so that all real-life operational doses will be bounded by the analyses in the EIS and protect all personnel involved. In practice, however, it is highly unlikely that the combination of conservative assumptions made in the EIS would be experienced. Detailed descriptions of the assumptions used in the EIS are found in Appendix C to the EIS, Marine Transport and Associated Environmental Impacts, and are briefly summarized in this paper.

One of the key assumptions in the assessment of radiation doses from transportation is, obviously, the dose rate of the package(s) transported. External radiation from an intact transportation cask must be below specified limits that control exposure of the handling personnel and general public. The U.S. limits are set forth in 49 CFR 173.441. The limit of interest established therein is 0.1 mSv/h (10 mrem/h) at any point 2 m (6.6 ft) from the vertical planes projected by the outer lateral surfaces of the transport vehicle. This limit is associated with an "exclusive-use" shipment, which is a shipment in which no other cargo is loaded in the container used for the foreign research reactor spent nuclear fuel transportation cask and the container is not off-loaded and restowed in transit, except as directed by the shipper. This does not mean that the vessel is used exclusively for foreign research reactor spent nuclear fuel, although experience has shown that shipments follow a dedicated ship arrangement and no change is expected because of insurance, routing, and other issues.

The EIS assumed that all packages transported has the maximum allowable surface dose rates and maximum allowable dose rates at 2 meters. Experience has shown that this is very conservative. As shown in Table 1, data on 31 foreign research reactor spent fuel casks received by the Savannah River Site under the new acceptance policy implemented in 1996 indicate that the average measured dose rate from the casks has been approximately less than one-tenth of the regulatory limit assumed in the analyses. One obvious reason for the low package dose rates is that, in general, much of the foreign research reactor spent nuclear fuel received has been out of the reactor for a significant amount of time prior to shipment, resulting in external dose rates much less than the regulatory limit. Due to the 13-year time frame of this program and the possibility that some of the spent nuclear fuel may be shipped with shorter fission product decay times than previous shipments, the program must be cautious in using currently seen dose rates in developing mitigative measures because those dose rates may not be fully representative of shipments later in the program.

The next assumption for dose estimation purposes was the method of cask handling and transport. For purposes of analysis, all spent nuclear fuel casks were assumed to be transported in a 20-foot ISO container for ease of handling and transport. The ship's crew was assumed to be present for cargo loading, but the actual cargo securing would be performed by shore-based workers. Once at sea, however, all cargo related activities such as daily inspections were assumed to be performed by ship's crew.

The type of vessel assumed for transport of the spent nuclear fuel was a breakbulk vessel. The EIS assumed that the breakbulk vessels could be either regularly scheduled commercial vessels or chartered vessels. Breakbulk vessels typically have a number of holds, decks within each hold for carrying cargo, and their own cargo handling equipment that could be used for loading spent nuclear fuel casks. The EIS assumed that two casks per vessel would be carried on each freighter, even though it was likely that more than two casks per shipment could be coordinated at the same time. The expectation was that the assumption of two casks per vessel should bound the incident-free analysis. The analysis assumed that both spent nuclear fuel casks were loaded into the same hold, resulting in a dose to the crew from the first cask loaded while the second cask was loaded into the same hold. If more than two spent nuclear fuel casks be shipped on the same vessel, it was assumed that the cargo loading would be limited to two spent nuclear fuel casks per hold. The EIS assumed that the crew would not receive any additional dose from the third, fourth, etc., cask while engaged in activities in the hold with the first two spent nuclear fuel casks.

The final key assumption relates to the time and distances the ship's crew and dock workers spend inspecting and handling the cargo. Once a day while at sea or in port, the Chief Mate, the Bosun, and an Engineer are assumed to enter each cargo hold to inspect the bilges and verify the lashings for the containers. Exposures were estimated based on assumed inspection times and distances for casks shipped at the exclusive-use external dose rate limit of 0.1 mSv/h at 2 m. A chartered voyage was assumed to last a total 18 days for a shipment of two casks, a commercial liner with stops was assumed to take 21 days. Shipboard inspections were assumed to take 20 minutes per day and involve three persons.

Table 1: Foreign Research Reactor Spent Fuel Shipment Cask Information

Cask Type	Surface dose rate (mSv/h)	0.3 meter dose rate (mSv/h)	Activity (TBq)	Elements	Transport Index
IU-04	ND	ND	1.6e3	26	3
IU-04	0.015	0.001	9e2	40	2
GNS-11	0.033	0.005	1.75e3	26	1.3
GNS-11	0.035	0.005	6.04e2	33	0.8
TN-7/2	0.015	0.01	1.84e3	64	8.33
TN-7/2	0.23	0.008	4.45e3	42	8.33
NAC-LWT	-	0.15	-	41	-
NAC-LWT	0.002	ND	1.67e0	21	2
NAC-LWT	0.005	ND	2.11e2	28	0.1
GNS-11	0.005	ND	2.15e3	33	0.5
GNS-11	0.002	ND	1.39e3	33	0.3
TN-7/2	ND	ND	4.79e3	39	8.3
TN-7/2	0.036	0.022	7.98e3	53	8.3
IU-04	ND	ND	5.1e2	36	0
IU-04	ND	ND	4.5e2	39	0
IU-04	ND	ND	3.7e2	39	0.4
JMTR	ND	ND	5.7e2	30	0.3
JMTR	ND	ND	5.9e2	30	0.3
TN-6/3	0.005	ND	5.1e0	1	-
TN-7/2	0.018	0.002	1.49e3	48	8.3
TN-7/2	0.005	0.003	2e3	64	8.3
GNS-11	ND	ND	6.21e3	33	3.1
GNS-11	ND	ND	7.39e2	26	0.4
NAC-LWT	0.005	0.0012	2.68e3	42	0.5
IU-04	ND	ND	2.22e1	40	1
IU-04	ND	ND	5.55e2	36	1
IU-04	0.005	0.0012	1.38e3	25	-
IU-04	0.005	0.0001	1.77e3	36	1
TN-7/2	0.005	0.0002	2.95e3	64	8.3
GNS-11	0.07	0.005	7.24e3	33	10.3
GNS-11	0.07	0.007	7.52e3	33	10.1

Table 1 (continued)

Cask Type	Surface dose rate (mSv/h)	0.3 meter dose rate (mSv/h)	Activity (TBq)	Elements	Transport Index
IU-04	ND	ND	1.6e3	26	3
IU-04	0.015	0.001	9e2	40	2
GNS-11	0.033	0.005	1.75e3	26	1.3
GNS-11	0.035	0.005	6.04e2	33	0.8
TN-7/2	0.015	0.01	1.84e3	64	8.33
TN-7/2	0.23	0.008	4.45e3	42	8.33
NAC-LWT	-	0.15	-	41	-
NAC-LWT	0.002	ND	1.67e0	21	2
NAC-LWT	0.005	ND	2.11e2	28	0.1
GNS-11	0.005	ND	2.15e3	33	0.5
GNS-11	0.002	ND	1.39e3	33	0.3
TN-7/2	ND	ND	4.79e3	39	8.3
TN-7/2	0.036	0.022	7.98e3	53	8.3
IU-04	ND	ND	5.1e2	36	0
IU-04	ND	ND	4.5e2	39	0
IU-04	ND	ND	3.7e2	39	0.4
JMTR	ND	ND	5.7e2	30	0.3
JMTR	ND	ND	5.9e2	30	0.3
TN-6/3	0.005	ND	5.1e0	1	-
TN-7/2	0.018	0.002	1.49e3	48	8.3
TN-7/2	0.005	0.003	2e3	64	8.3
GNS-11	ND	ND	6.21e3	33	3.1
GNS-11	ND	ND	7.39e2	26	0.4
NAC-LWT	0.005	0.0012	2.68e3	42	0.5
IU-04	ND	ND	2.22e1	40	1
IU-04	ND	ND	5.55e2	36	1
IU-04	0.005	0.0012	1.38e3	25	-
IU-04	0.005	0.0001	1.77e3	36	1
TN-7/2	0.005	0.0002	2.95e3	64	8.3
GNS-11	0.07	0.005	7.24e3	33	10.3
GNS-11	0.07	0.007	7.52e3	33	10.1

Once at the port of entry, all casks of the spent nuclear fuel would be off loaded. Crew members would be present for off-loading but shore-based workers would perform off loading activities. Once the spent nuclear fuel cask is over the rail of the ship, the ship's crew would not be in close proximity to the cask. As a result, no ship crew personnel are assumed to be involved with any of the activities associated with disengaging the spent nuclear fuel container from the handling gear or in securing the container to any transport vehicle used to move the container off the pier.

Based on these assumptions, the EIS estimated the maximum individual dose per shipment on a regularly scheduled commercial vessel as 66 mrem to the Chief Mate and Bosun, a dose below the 1 mSv/y (100 mrem/y) limit. If the assumption was made that the same vessel and crew was used for as many shipments as possible in one year, the maximum individual dose to a crew member would be approximately 600 mrem. This assumes nine trips per year based on the average voyage length of all shipments and results in the ships' crew being exposed to the foreign research reactor spent nuclear fuel shipments for 189 days a year. Since travel time to a port of loading would be required, and most ship crews are rotated on a three or six month basis, the assumption of nine trips should bound the dose for any individual members of dedicated crews, even when trips are shorter than the assumed average of 21 days for a regularly scheduled commercial liner. The annual dose of approximately 600 mrem exceeds the 100 mrem annual limit for a member of the general public, and would therefore require mitigation.

Due to the larger number of casks on a chartered vessel, the EIS estimated that the largest annual dose to a crew member is approximately 1,668 mrem (approximately 1.7 rem or 0.017 mSv). This is based on an estimated exposure of 238 mrem per voyage and seven voyages per year with each voyage taking an average of 18 days. Seven voyages per year using a chartered vessel is sufficient to ship all transportation casks to be shipped in an average year assuming that 721 cask shipments are made over a 13-year period.

The analysis in the EIS also looked at spent fuel transport assuming that the spent fuel transported had radiation characteristics similar to the historic dose rates. For this analysis, all other assumptions regarding voyage length, crew activity (time and distance from the spent nuclear fuel cask), number of shipments, and the assumptions made to estimate annual doses remained the same as in the analysis performed using the external dose rates derived from the exclusive-use regulatory limit of 10 mrem (0.1 mSv) per hour at 2 m (6.6 ft) from the surface of the shipping container. Using the historic dose rates, the maximum dose to an individual per regularly scheduled commercial vessel shipment would be 6.6 mrem (0.066 mSv), and the annual maximum individual dose would be 60 mrem (0.6 mSv). This dose is calculated assuming that the same crew member is involved in nine separate voyages transporting two spent nuclear fuel casks each during a single year. These doses are an order of magnitude lower than the corresponding doses calculated using the exclusive-use regulatory external dose rates. The calculated maximum individual dose is well below the maximum allowable annual dose to a member of the public of 100 mrem (1 mSv).

The results of the analyses in the EIS indicate that only in special circumstances could some individual crew members receive doses that exceed the limit established by DOE and the NRC for exposure of a member of the public. These exposures are a particular concern when the dose rate from the casks are near or at the regulatory limit.

Mitigation Action Plan

Because of the potential for individuals associated with the spent fuel shipments in special circumstances to exceed established radiation protection limits, DOE developed and implemented a Mitigation Action Plan. Data required for implementation of the Mitigation Action Plan are: 1) the measured external radiation levels for each spent fuel transportation cask (to be obtained prior to the ship leaving port with the loaded cask(s) on board), 2) the roster of the ship's crew (to be obtained prior to the ship leaving port with the loaded cask(s) on board), and 3) the roster of U.S. ground transportation workers that will be used (to be supplied prior to the ship being unloaded). These data are supplied by the DOE shipping contractor or the foreign research reactor operators in accordance with contractual obligations.

The current approach taken to reduce the possibility of a ship's crew member or a U.S. transportation worker receiving a radiation dose in excess of the annual limit consists of the following steps:

1. For each shipment (prior to leaving the foreign port), estimate, using loaded cask radiation survey data, the probable doses that will be received by —
    a. The ship's crew members
    b. The U.S. ground transportation workers
2. Add the highest estimated dose for the current shipment for each group to the highest cumulative doses received by an individual in each group for previous shipments in the current calendar year.
3. For maximum individual totals less than 100 mrem (from step 2, above), no mitigation action is necessary.
4. For maximum individual totals equal to or greater than 100 mrem (from step 2, above), screen the records of the current ship's crew members and the U.S. ground transportation workers for individuals who have actually accumulated exposure in the current calendar year.
5. Take action, in conjunction with the research reactor operator and the DOE shipping contractor to limit additional exposure to any individuals identified (step 4, above).

If the sum is 100 mrem (1 mSv) or above for the year, the ship's crew roster for the current shipment will be reviewed to determine if any individuals on the roster for the current shipment are at risk of receiving a cumulative dose in excess of 100 mrem (1 mSv) during the current shipment. The DOE shipping contractor or the research reactor operator, as applicable depending on the country of origin of the spent fuel, will be notified of any individuals in this situation. A course of action, mutually acceptable to both DOE and the party responsible for the shipment, will then be initiated. Possible courses of action include, but are not limited to:

- replacing the affected crew member(s)
- restricting the exposure of affected crew member(s) by controlling their proximity to and their time spent near the casks
- altering the duties of the crew member(s)
- providing the crew member(s) with real-time radiation dosimeters
- certifying crew member(s) as radiation workers
- combinations of the above.

Because DOE will not have direct control over the transportation workers involved, the requirement to carry out mitigative actions will be the responsibility of the DOE shipping contractor or the foreign research reactor operators, depending on the country of origin of the spent fuel. DOE will require, by contract clause, that the foreign research reactor operators comply with this Mitigation Action Plan.

Program Experience

As of the end of January 1998, the DOE will have accepted five shipments of foreign research reactor spent nuclear fuel under the new program. These shipments used thirty-one casks, seven ship voyages, and one truck shipment. The number of casks on the vessels has ranged from two to eight. Two vessels have been used twice in the first two years of this program. One of these vessels will be used a third time in May involving three spent fuel casks, but the vessel has not been used in this calendar year.

Assumptions in the EIS with respect to the vessel and operational experience are different in several key areas, but the assumption of dedicated charter vessels has proven to be valid. All chartered vessels have been breakbulk vessels, but the internal hold configuration has involved one large hold with removable intermediate decks. As a result, more than two containers have been present in a hold, with a total of eight as a maximum. Second, vessel transits are taking longer than assumed in the EIS because the EIS assumed average vessel speeds of 15 kts. In reality, most of the vessels used to transport the spent fuel are averaging speeds of about 11 kts. The effect of this lower speed is to increase the potential number of daily inspections, but the low package dose rates and the shorter overall inspection times per cask because of the co-location of all casks in the same hold has kept exposures to non-detectable levels.

The assumption was made in the EIS that the same vessel would be used for several shipments. This assumption resulted from the realization that there are few carriers willing to transport spent nuclear fuel and meet the schedule and route requirements of the program. In addition, there are International Maritime Organization and U.S. Coast Guard requirements that must be met for the vessels. Experience is showing that there are several vessels dedicating themselves to the lucrative niche market of spent fuel transport. As a result, the program is witnessing the repeated use of the same vessels. Even though the program has already seen two vessels more than once, to date, the same vessel has not been used more than once in the same calendar year. However, one crew member has been present on two different ships. The individual was not involved in daily cargo inspection activities, but validates as reasonable the assumption in the EIS that the same crew members could be aboard repeat vessels or on different vessels seen within the same year. Looking ahead over the next several years, DOE is expecting four to six shipments per year. It is entirely possible that the individual members of the ships crews could be used more than once in a calendar year and DOE will continue to monitor this situation.

As shown in Table 1, the package dose rates for the spent fuel received to date have been well below the regulatory limits. All spent fuel has been received on skids or in containers that mate with the standardized 20-foot container handling equipment available at ports. The times associated with cask inspection and unloading are proving to be compatible with the estimates in the EIS. The EIS assumed cask unloading times of 65 minutes per cask. Operational experience has shown that cask unloading activities (radiation surveys, removal of firefighting headers, removal of lashing, and rigging of container for offloading) take an average of 20 minutes per container. At sea inspection times of 4 to 15 minutes per cask are being reported and involve one to two individuals on a daily basis. In some cases, company assigned radiation protection personnel have accompanied the shipment and taken responsibility for cargo inspections. These personnel have worn dosimetry devices and have reported no measurable doses.

The crew member exposures estimated in the EIS that led to the implementation of the Mitigation Action Plan have been demonstrated as being very conservative. To date, no detectable exposures have been reported for any ship crew members. In fact, the only non-radiation worker exposure reported has been that of a dock worker. During two different shipments, one dock worker received an exposure of 4 mrem (0.04 mSv). The dock worker was a different individual for the two shipments. In both cases, the worker performed cargo handling activities for the shipments primarily involving guidance of the cask onto rail cars on the piers and disengagement of the lifting devices.

Table 2 contains a brief summary highlighting comparisons between assumptions made in the EIS regarding general population member exposure for spent fuel transport by sea and operational experience. The comparisons are extremely useful in evaluating the conservatism built into the EIS analysis and for developing more realistic dose estimates of marine transport activities when appropriate.

Summary

Experience has shown that the analyses of marine transport of spent fuel in the EIS were conservative. It is anticipated that for most shipments, the external dose rate for the loaded transportation case will continue be near the historic dose rates, which would not cause any personnel to exceed radiation exposure limits for the public. Package dose rates well below the regulatory limits and personnel work practices following ALARA principles are keeping human exposures to minimal levels. However, the potential for future shipments with external dose rates closer to the exclusive-use regulatory limit suggests that DOE should provide a means to assure that individual crew members do not receive doses in excess of the public dose limits. As a minimum, the program will monitor cask dose rates and continue to implement administrative procedures that will maintain records of the dose rates associated with each shipment, the vessel used, and the crew list for the vessel. DOE will continue to include a clause in the contract for shipment of the foreign research reactor spent nuclear fuel requiring that the Mitigation Action Plan be followed.

References

DOE, 1996a, Record of Decision for the Final Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Nuclear Fuel, U.S. Department of Energy, Washington, D.C., May 1996.

DOE, 1996b, Environmental Impact Statement on a Proposed Nuclear Weapons Nonproliferation Policy Concerning Foreign Research Reactor Spent Nuclear Fuel, U.S. Department of Energy, Washington, D.C., DOE/EIS-0218F, February 1996.

Table 2: Comparison of EIS Assumptions and Operational Experience

	EIS Assumption	Operational Experience
Vessel	Charter Breakbulk	Charter Breakbulk
Vessel Speed (kts)	15	~11
Voyage Duration for charter	18 days (for 2 casks)	varies
Casks per hold	2	2 to 8
Casks per charter vessel	8	8
Cask Dose Rate (mSv/h at 0.3 m)	0.23	0 - 0.15 (average = 0.01)
Number of Crew Inspecting Fuel Daily	3	1-2
Number of Dedicated Radiation Protection Personnel on Board	0	0-1
Time for Daily At-Sea Inspection per cask	10 minutes	4-15 minutes
Voyages per year for same crew	9	1
Cask Handling Time for Off loading	65 minutes	20
Maximum crew member dose per voyage	2.38 (charter) 0.66 (commercial liner)	ND
Expected crew member dose per voyage	0.24 (charter) 0.066 (commercial liner)	ND
Maximum annual shore worker dose	>1	0.04